A new approach to detection and attribution of ocean thermal expansion

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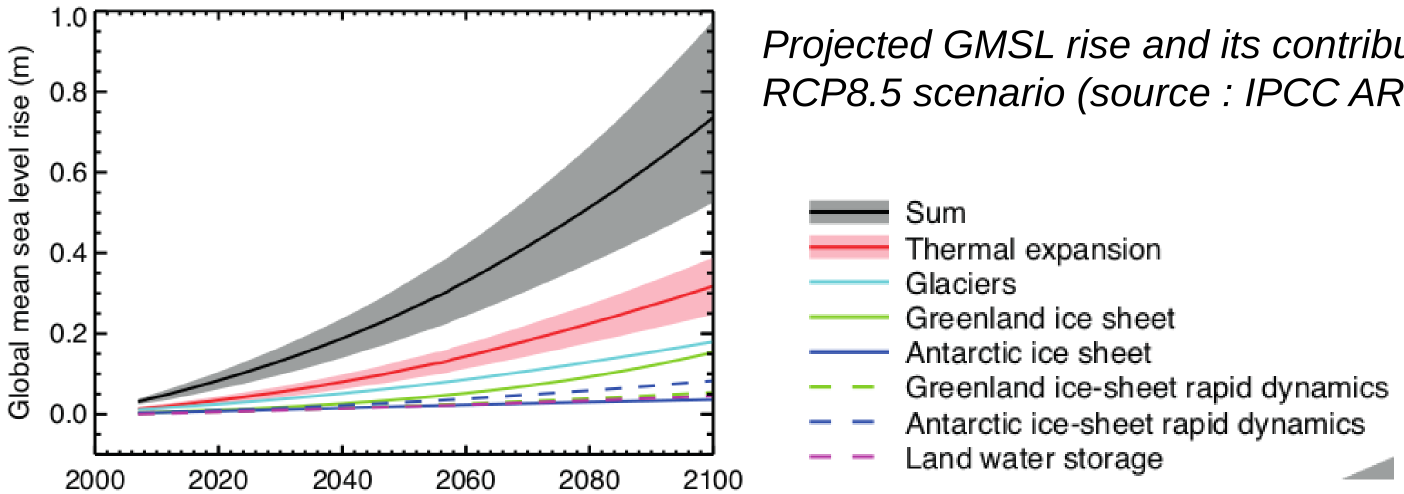
Context

- Tide gauges and satellite-based altimetry provide evidence that the global mean sea level (GMSL) has been rising during the last century with an accelerating rate (Church et al. 2013) :
  - 2.0±0.3 mm/y over 1971-2010 ; 3.2±0.4 mm/y over 1993-2012
- Ocean thermal expansion is one of the main contributors :
  - 40 % over 1971-2010 ; 30 % over 1993-2012
- In the context of global warming, thermal expansion is expected to keep increasing and to contribute by 30-35 % to the GMSL by 2100



Projected GMSL rise and its contributions for RCP8.5 scenario (source : IPCC AR5, Fig. 13.11)

Scientific questions

- What is the influence of natural, anthropogenic external forcings and internal variability on the thermosteric sea level changes (part of sea level related to thermal expansion) ?
- Can we quantify the contribution of each external forcing ?
- Globally ? … Regionally ?

- Detection and Attribution (D&A) methods, by comparing simulations to observations, can estimate the contributions from each external forcing
- Ribes et al. (2015) developed a new D&A method that allows to :
  - Estimate the contributions from each forcing
  - Reduce the uncertainties for each estimated contribution
  - Take in additionnal information from the variable of interest over a different region/period
- We first test this method on the global mean thermosteric sea level (GMTSL) trends

Method and data

Detection and Attribution method (1/2)

> Ribes et al. (2015) developed a new D&A method :

$$Y^* = \sum X_i^*$$
$$= X_{HIST}^*$$
$$= X_{NAT}^* + X_{ANT}^*$$

Observations → Y^*

Simulated response to external forcing i → X_i^*

to ALL forcings → X_{HIST}^*

to NAT and ANT forcings → X_{NAT}^*, X_{ANT}^*

$$X_i = X_i^* + \varepsilon_{X_i},$$
$$Y = Y^* + \varepsilon_Y,$$

Errors → ε_{X_i}, ε_Y

Traditionnal linear regression based D&A

$$Y^* = \sum_{i=1}^{n_f} \beta_i X_i^*$$

Best estimator

(based on likelihood maximization)

$$\widehat{X}_i^* = X_i + \frac{\Sigma_{X_i}}{\Sigma_Y + \Sigma_X}(Y - X)$$

$$\Sigma_{\widehat{X}_i^*} = \left(\frac{1}{\Sigma_{X_i}} + \frac{1}{\Sigma_Y + \sum_{j \neq i} \Sigma_{X_j}}\right)^{-1}$$

Detection and Attribution method (2/2)

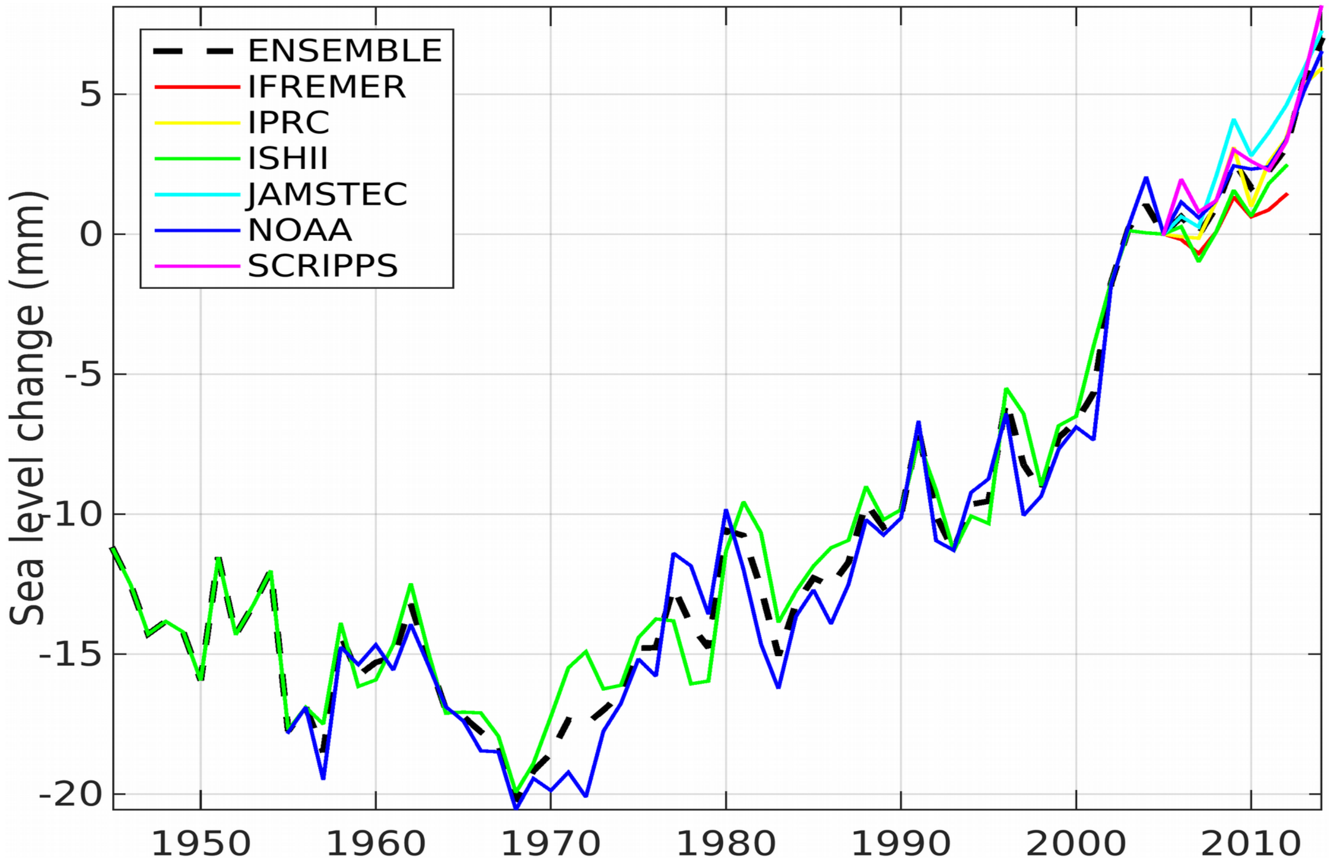
$$Y^* = X^*_{NAT} + X^*_{ANT}$$

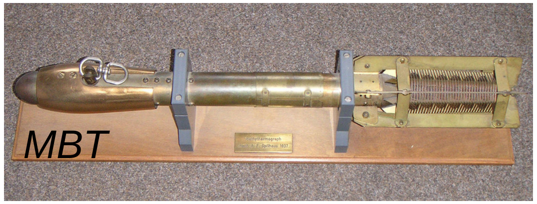
- Univariate case : $$y = x_{NAT} + x_{ANT}$$
- Bivariate case : $$\begin{pmatrix} y \\ y' \end{pmatrix} = \begin{pmatrix} x_{NAT} \\ x'_{NAT} \end{pmatrix} + \begin{pmatrix} x_{ANT} \\ x'_{ANT} \end{pmatrix}$$

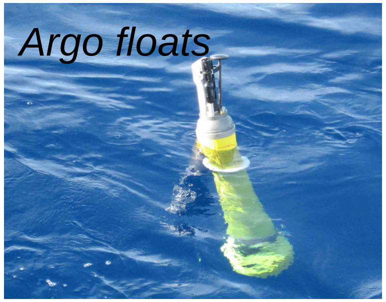
> We apply this method to the global mean 0-700m thermosteric sea level trends from 1957 to 2005.

Measurements

Observed global mean 0-700m thermosteric sea level changes for different datasets

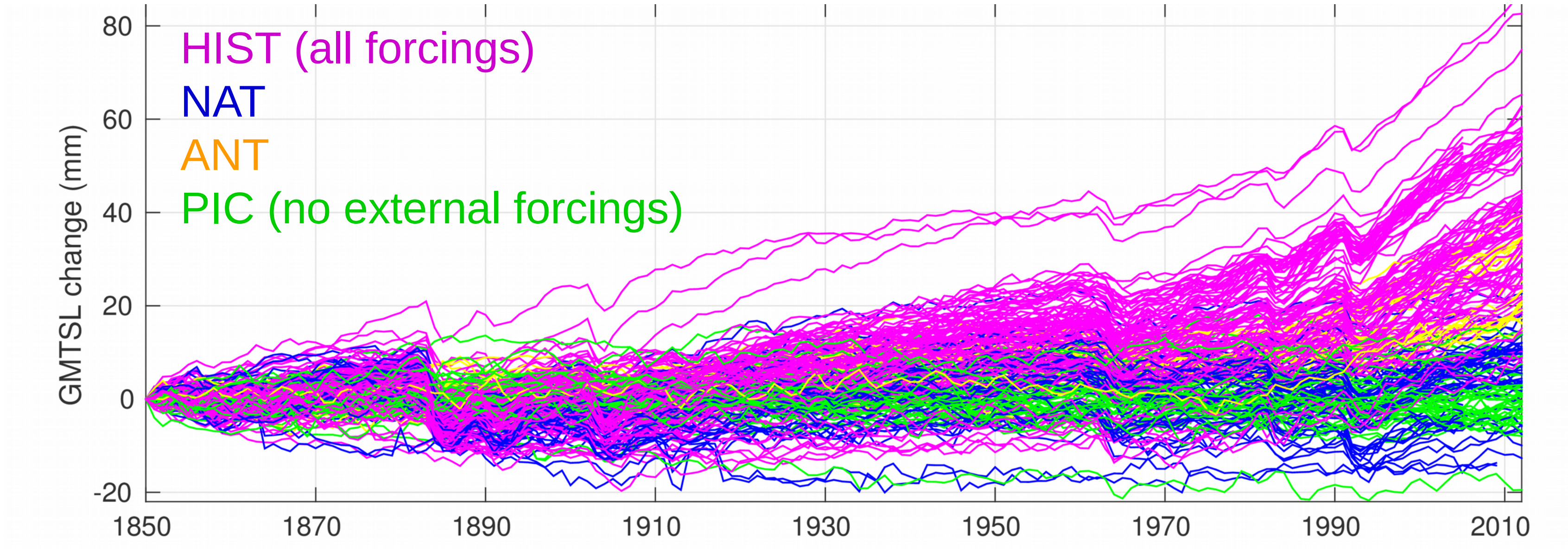






Models and simulations (1/2)

- Simulations are issued from CMIP5 and cover the period 1850-2012 :
  - HIST experiments include all external forcings
  - NAT experiments include natural forcings only (volcanism, solar input variations, etc)
  - ANT=HIST-NAT include all anthropogenic forcings (greenhouse gases, anthropogenic aerosols and ozone, etc.)
  - PIC experiments are the unforced control runs



Models and simulations (2/2)

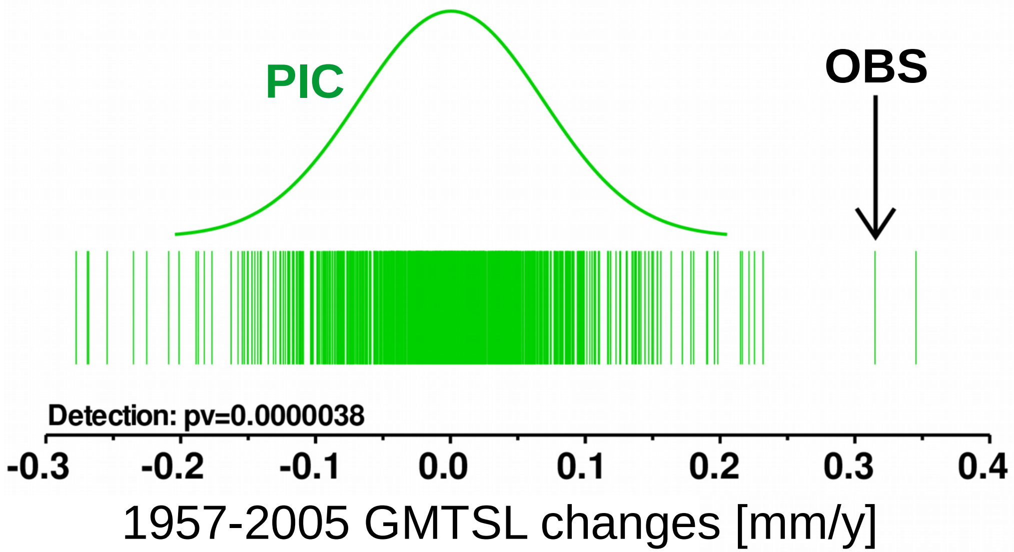
- For each model, at least HIST and PIC experiments are available, sometimes with several initial conditions for the same forcing (= multiple realisations)

Number of models and realisations available for each forcing

Experiment	# of models	# of realisations
HIST	38	123
NAT	17	58
ANT	17	32.6 (equiv #)
PIC	38	943 (# segts)

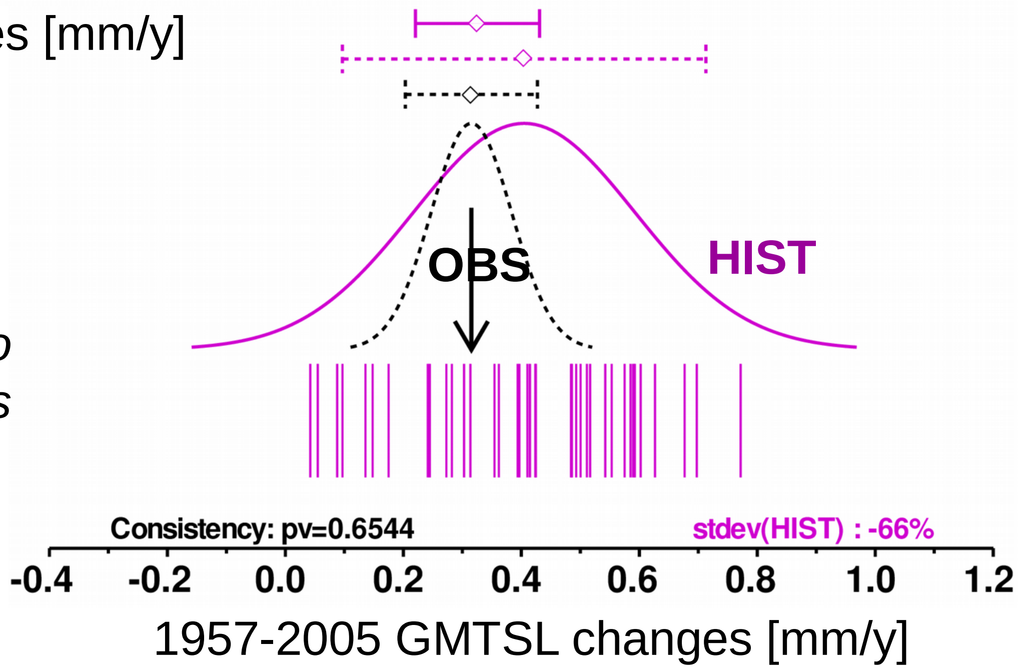
Results

Univariate case (1/2)

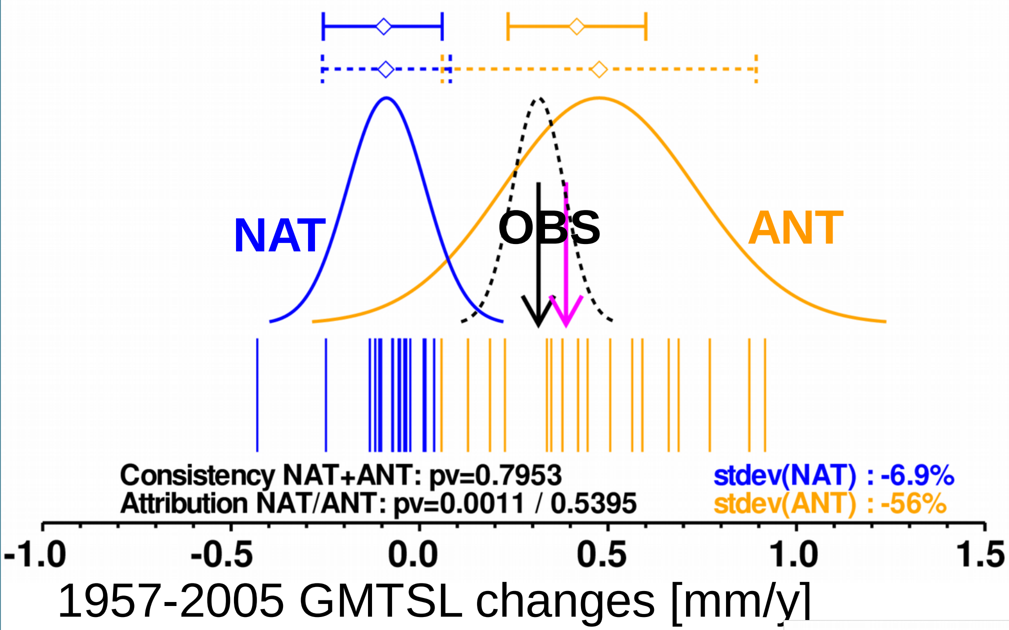


Comparison of observations to unforced control simulations

Comparison of observations to HIST (all forcings) simulations

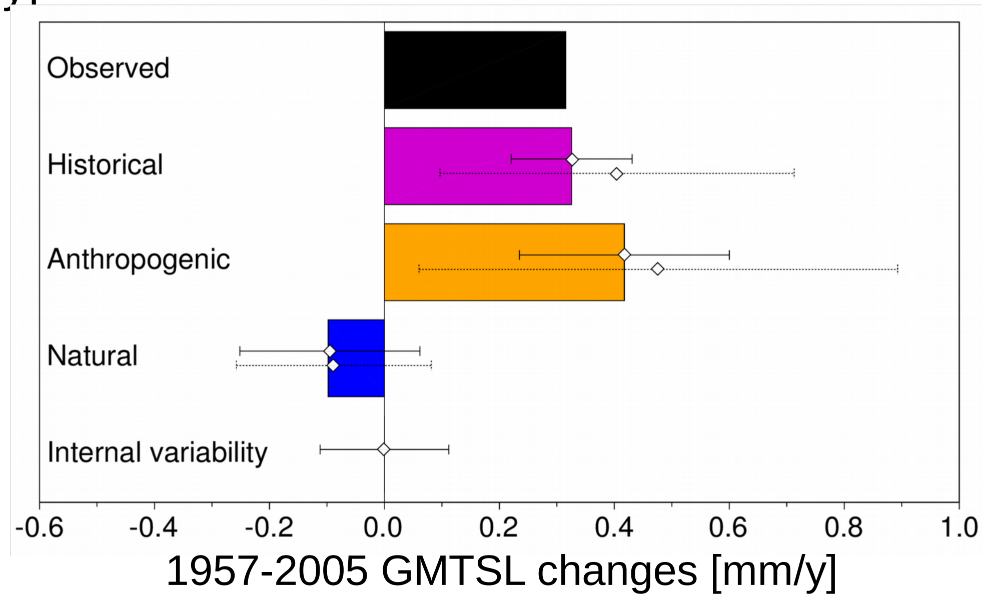


Univariate case (2/2)



Comparison of observations to NAT and ANT forcing-only simulations

Contribution of each forcing and associated uncertainties issued from multi-model mean (dotted lines) and from D&A best estimators (continuous lines)



Bivariate case (1/2)

- Our variable of interest : 1957-2005 Global MTSL trend
- In the bivariate case, we choose a secondary region & period (e.g. Indian Ocean over 1993-2012)
- We browse different regions/periods, looking for a maximal reduction of the standard deviation :

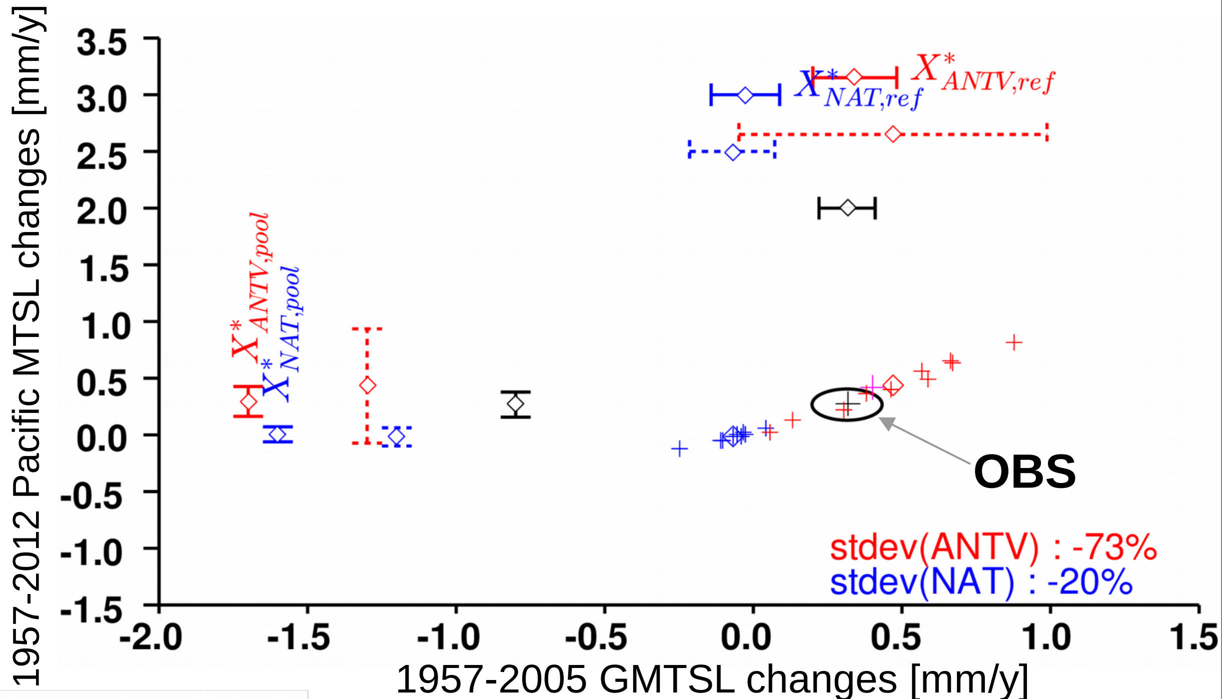
	HIST	NAT	ANT
Univariate – global2/1957-2005	66 %	7 %	56 %

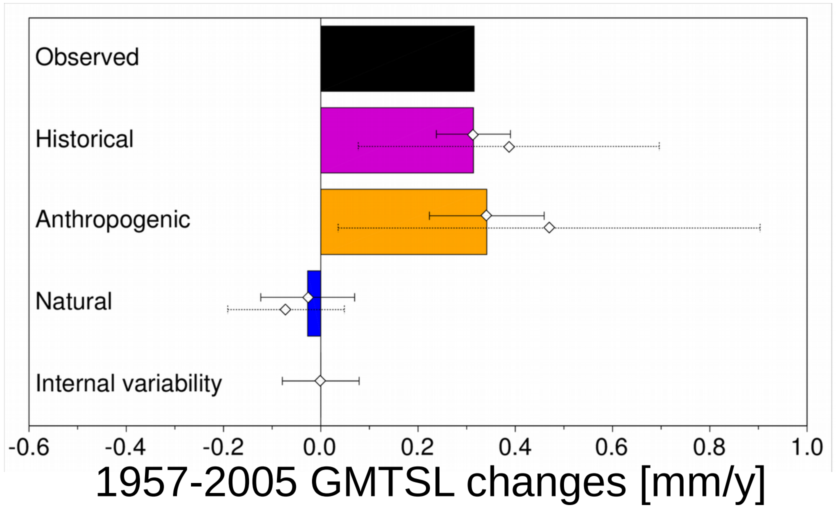
B constraints	HIST	NAT	ANT
global2/1957-2012	75,8 %	6,0 %	70,1 %
global2/1971-2012	75,4 %	4,5 %	69,2 %
global2/1993-2012	75,9 %	7,1 %	70,3 %
global2/1957-2005	NA	NA	NA
global2/1971-2005	75,5 %	8,5 %	58,3 %
global2/1993-2005	76,0 %	17,3 %	62,5 %
northernhemisphere/1957-2012	75,6 %	4,0 %	69,3 %
northernhemisphere/1971-2012	75,3 %	3,5 %	68,9 %
northernhemisphere/1993-2012	75,5 %	4,6 %	69,6 %
northernhemisphere/1957-2005	75,6 %	8,4 %	58,2 %
northernhemisphere/1971-2005	75,5 %	7,8 %	57,9 %
northernhemisphere/1993-2005	75,7 %	18,0 %	62,1 %
southernhemisphere/1957-2012	75,3 %	3,8 %	68,8 %
southernhemisphere/1971-2012	75,4 %	4,6 %	69,2 %
southernhemisphere/1993-2012	76,0 %	8,0 %	70,3 %
southernhemisphere/1957-2005	75,6 %	8,6 %	58,3 %
southernhemisphere/1971-2005	75,5 %	8,3 %	58,3 %
southernhemisphere/1993-2005	76,0 %	8,7 %	58,8 %

B constraints	HIST	NAT	ANT
atlantic/1957-2012	75,6 %	4,2 %	68,7 %
atlantic/1971-2012	75,4 %	3,5 %	68,8 %
atlantic/1993-2012	75,4 %	6,3 %	69,9 %
atlantic/1957-2005	75,6 %	8,1 %	58,4 %
atlantic/1971-2005	75,5 %	7,8 %	58,2 %
atlantic/1993-2005	75,8 %	15,2 %	61,2 %
pacific/1957-2012	75,4 %	19,6 %	72,8 %
pacific/1971-2012	75,3 %	10,4 %	70,5 %
pacific/1993-2012	76,2 %	4,9 %	69,4 %
pacific/1957-2005	75,5 %	9,3 %	58,7 %
pacific/1971-2005	75,6 %	8,1 %	58,3 %
pacific/1993-2005	75,8 %	12,0 %	60,1 %
indian/1957-2012	75,3 %	4,0 %	68,9 %
indian/1971-2012	75,3 %	3,8 %	68,8 %
indian/1993-2012	75,6 %	5,5 %	69,4 %
indian/1957-2005	75,7 %	9,5 %	58,5 %
indian/1971-2005	75,6 %	10,3 %	58,8 %
indian/1993-2005	75,8 %	10,6 %	59,4 %
southernocean/1957-2012	75,7 %	3,5 %	68,9 %
southernocean/1971-2012	75,3 %	4,1 %	68,8 %
southernocean/1993-2012	75,5 %	8,9 %	70,2 %
southernocean/1957-2005	76,0 %	7,9 %	58,7 %
southernocean/1971-2005	75,6 %	8,4 %	58,1 %
southernocean/1993-2005	75,7 %	9,6 %	58,9 %

Bivariate case (2/2)

> Pacific/1957-2012





Contribution of each forcing and associated uncertainties issued from multi-model mean (dotted lines) and from D&A best estimators (continuous lines)

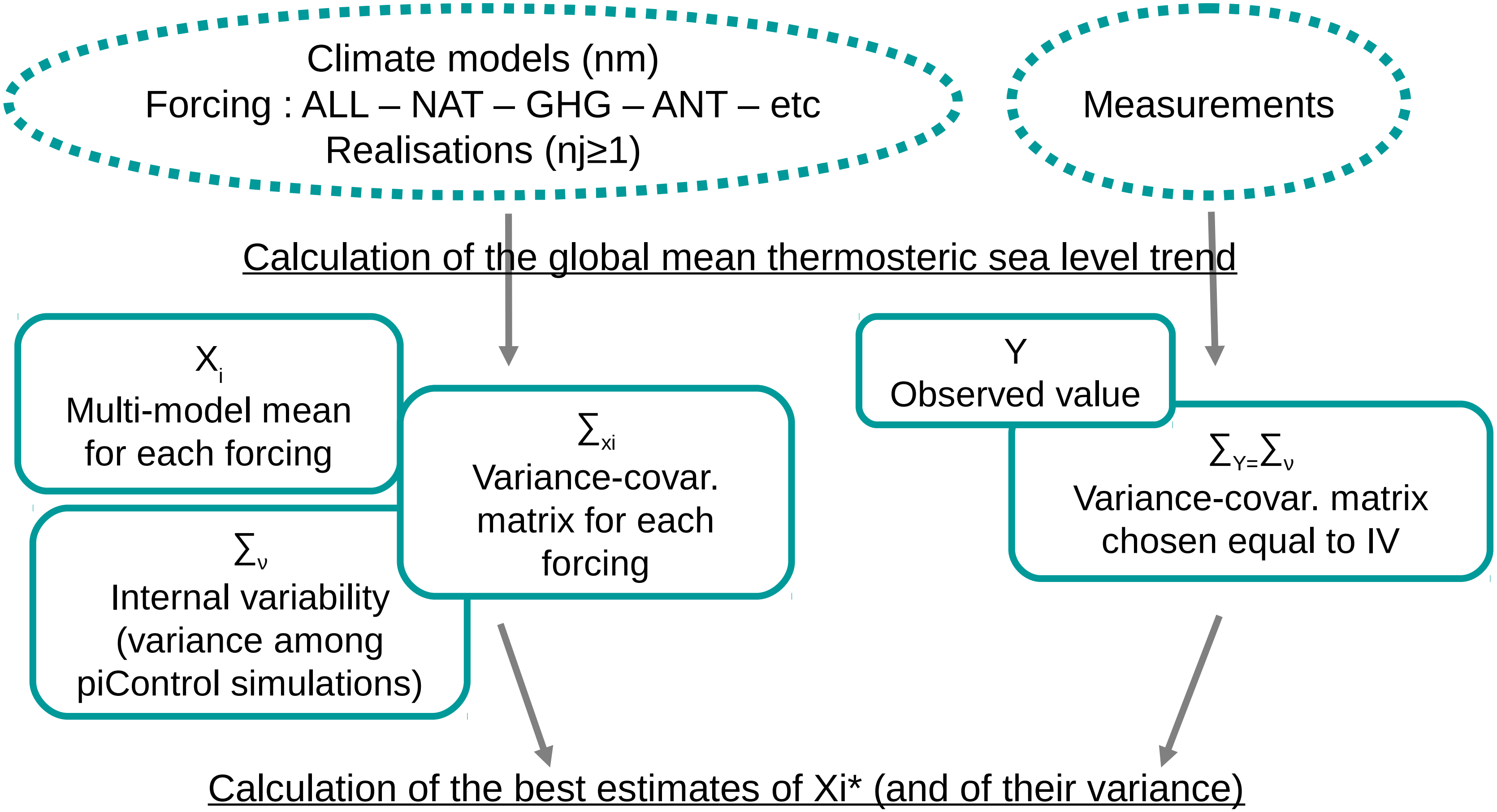
Conclusion

- Results on GMTSL trends are consistent with previous studies
- The bivariate case gives promising results for regional analyses
- This new D&A method accounts for a climate modelling uncertainty and allows computing a reduction of the uncertainties of each contribution
- First time that this type of enhanced method is applied to oceanic variables : the long-term memory of those variables can bring interesting constraints when assessing the contribution from each forcing

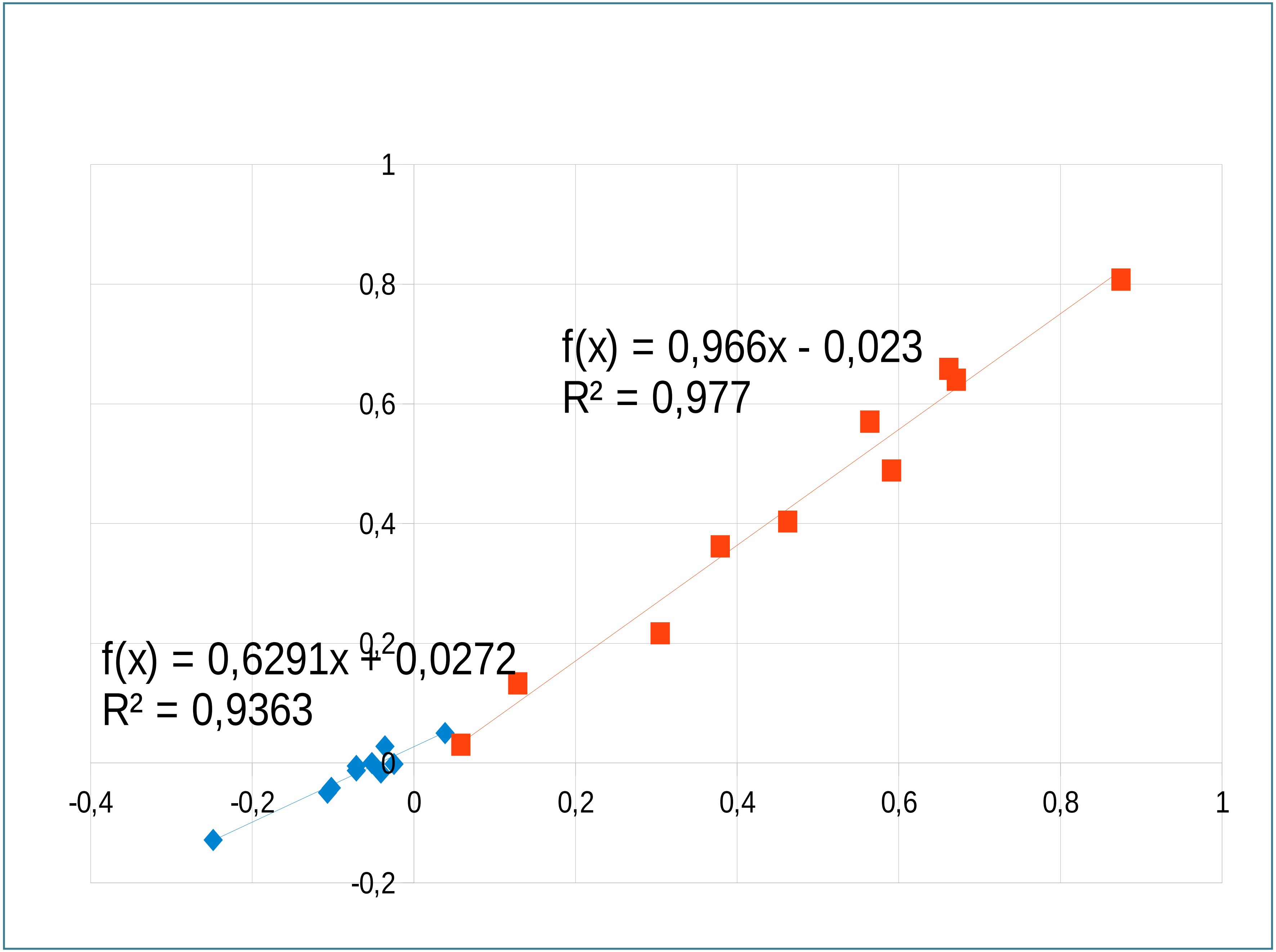
Next steps

- Further investigation of this method potential for regional analyses
- Assessment of the contribution of greenhouse gases, aerosols, ozone forcings separately
- Application of this method to the full sea level variations, using satellite altimetry and tide-gauge measurements

Detection and Attribution method



$$\widehat{X}_i^* = X_i + \frac{\Sigma_{X_i}}{\Sigma_Y + \Sigma_X} \left(Y - X \right), \qquad i = 1, \ldots, n_f$$



1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,2
0
0,2
0,4
0,6
0,8
1
f(x) = 0,966x - 0,023
R² = 0,977
f(x) = 0,6291x + 0,0272
R² = 0,9363